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MEMS Rate Sensors for Space

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ABSTRACT

Micromachined Electro Mechanical System (MEMS) Rate Sensors are an enabling technology for Nanosatellites. The recent award of a Nanosatellite program to the Goddard Space Flight Center (GSFC) underscores the urgency of the development of these systems for space use. The Guidance Navigation and Control Center (GNCC) at the GSFC is involved in several efforts to develop this technology. The GNCC seeks to improve the performance of these sensors and develop flight ready systems for spacecraft use by partnering with industry leaders in MEMS Rate Sensor development. This paper introduces Microgyros and discusses the efforts in progress at the GNCC to improve the performance of these units and develop MEMS Rate Sensors for space use.

INTRODUCTION

Micromachined Electro Mechanical System (MEMS) Rate Sensors offer many advantages that make them attractive for space use. They are smaller, consume less power, and cost less than the systems currently available. MEMS Rate Sensors however, have not been optimized for use on spacecraft. This paper summarizes the state of the art of these devices and describes work being done by the Goddard Space Flight Center and its partners in developing MEMS Rate Sensors systems for space use.

Spacecraft designers are striving to replace traditional heavy, power-hungry mechanical gyro systems with lightweight and extremely reliable solid state rate sensing systems. One such system is the micromachined

gyroscope. These systems offer extremely small size (about 8 in³) low weight (less than 3 lbs.), low power (3 watts), and offer the potential of much lower cost than the existing technology gyros used in space applications.

Many satellites of the future will be much smaller than those currently being produced. Hundreds of "nano-satellites" launched and released into various orbits for space and earth science missions have been proposed. The Nanosat mass and power budgets for an entire Attitude Control System will be less than that currently allocated for a single ACS component. The potential for small size and low cost of the MEMS rate sensor make it an attractive option for these future satellites.

Currently, MEMS Rate Sensor systems are being produced for terrestrial and missile applications. Therefore they have relatively coarse performance, a large rate range (up to 1000 deg/sec), and are not radiation hardened. Before this technology can be used for attitude control on spacecraft, design issues must be addressed.

To address these design issues, the Guidance Navigation and Control Center (GNCC) at the Goddard Space Flight Center (GSFC) and its partners are involved in work that seeks to optimize the MEMS Rate Sensor and develop a MEMS based Inertial Reference Unit (IRU) for space use. This paper will describe this work and future work planned in this area.

MICROMACHINED ELECTROMECHANICAL SYSTEM (MEMS) RATE SENSORS

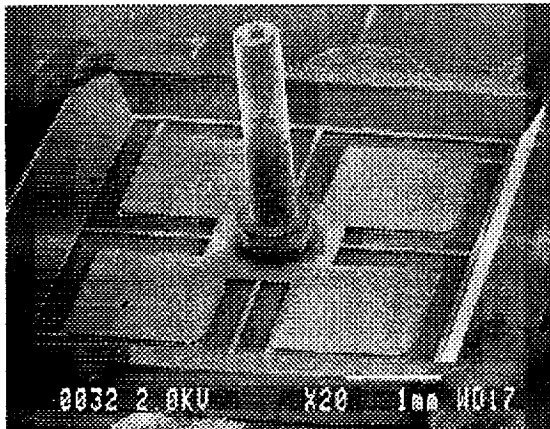
The MEMS Rate Sensor (also known as Microgyro) uses an oscillating mass to measure rotational rate. Typically, the mass oscillates in one axis and as the body is rotated, coriolis forces cause a change in the line of action of the oscillation of the mass. This change is measured and is proportional to the rotational rate of the body.

Microgyro configurations vary greatly, but in most cases, the fundamental operation of the sensor is typical. A mass is forced into oscillation by electrostatic means. This mass is supported by spring members that are attached at one end to the mass and at the other end to a substrate. When the body rotates about its sensitive axis, coriolis forces cause the mass to oscillate with a component normal to the drive axis. This normal component

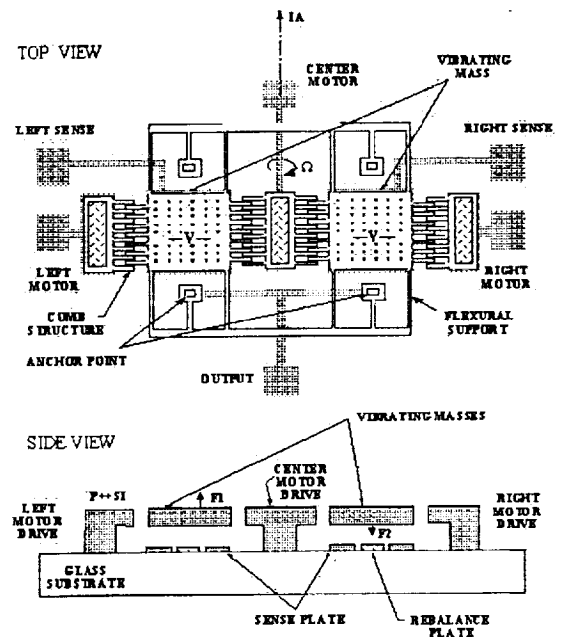
is sensed by capacitive means and is proportional to the rotational rate of the body.

MICROGYRO DESIGNS

There are many different microgyro configurations in existence however the high performance units seem to display similar performance which is in the 1-10 deg/hr range (over constant temperature). Several examples of various sensor element designs are shown. Despite the significant differences in sensor design, these units all display similar performance.



JPL Microgyro



Draper Laboratory Gyro

MICROGYROS FOR NANOSAT

The microgyro is the only existing inertial sensing technology that appears to be capable of meeting the requirements for Nanosatellites. Flight ready Microgyro systems need to be developed in the very near future to support Nanosatellite programs.

Goddard's Nanosat Constellation, targeted for 2003 launch, consists of three spacecraft to validate methods of operating several spacecraft in the Earth's magnetic field. Each Trailblazer spacecraft will be an octagon 16 inches across and 8 inches high. The mission will cost \$28 million and will be launched as a secondary payload on an expendable launch vehicle.

Results from the Trailblazer mission will be used to design future missions using constellations of lightweight (about 44 pounds), highly miniaturized autonomous spacecraft. One proposed constellation of up to 100 spacecraft positioned around the Earth will monitor the effects of solar activity that can affect spacecraft, electrical power and communications systems. Others will study global precipitation and the atmospheres of other planets.

Nanosatellites have arrived, and Microgyros will be needed to support their missions. To this end, it is estimated that Microgyro performance will need to improve at least one order of magnitude. This is based on a cursory survey of NASA missions showing the coarsest pointing requirements to be about 0.2 degrees. Assuming a low earth orbit satellite control system that provides a once per orbit attitude update, this roughly correlates to a gyro drift requirement of 0.1 deg/hr.

MICROGYRO PERFORMANCE IMPROVEMENTS

Microgyro performance has improved significantly over the past few years. However these systems still exhibit greater than 1 deg/hr drift at room temperature and performance over varying temperature in the 10 to 40 deg/hr range.

To close the gap between current microgyro performance and spacecraft requirements, efforts are being made to improve the performance of the microgyro. Two areas of focus have been electronics design and, to a lesser extent, sensor element design.

Improvements in microgyro performance can be gained through improved electronics design by reducing electronics noise and parasitic capacitance, and carefully selecting components for low noise performance.

The reduction of both bandwidth and dynamic range is being investigated as a method to improve performance. Most current Microgyro systems have dynamic ranges of about ± 1000 deg/sec and bandwidths of over 100 Hz. Typical spacecraft requirements for dynamic range are ± 20 deg/sec (or less) and for bandwidth are typically less than 10 Hz. Draper Laboratory, under contract to the GSFC, is investigating how changes in dynamic range and bandwidth affect performance.

Microgyro performance is also a function of the configuration of the sensing element. Work is just beginning at the GNCC in this area with the recent arrival of MEMS design and analysis software. While it is expected that performance can be improved, the magnitude of improvement has not been quantified.

Significant performance gains are expected to be realized with high fidelity temperature compensation. Thermal effects on the output of the gyro are large. This is evident from the order of magnitude degradation in drift performance over varying temperature.

A short-term performance goal of 0.1 deg/hr is expected to be reached with the optimization of electronics design and the implementation of temperature compensation and/or temperature control. This performance level is consistent with the requirements for some spacecraft. A mid-term goal would be to demonstrate 0.01 deg/hr drift. This level of performance would support a significant portion of future missions. The long term performance goal has no bound; work will continue to demonstrate the maximum level of performance of these sensors.

CURRENT GNCC INVOLVEMENT

The Microgyro work being done at the GNCC encompasses several separate efforts. Work is being done with JPL, APL, Kearfott Corp. and Draper Laboratory to develop MEMS rate sensors for space.

Goddard is working with JPL and APL to develop a Micronavigator. The micronavigator will be a 2 inch cube that provides attitude and position information. It will contain three microgyros, three micro accelerometers, GPS and processing capability. The unit will use the JPL Microgyros which continue to be developed. This exciting and challenging program is just getting underway and is planned to last about 4 years.

Work is being done with Kearfott Corp. to develop a three axis Micro Inertial Measurement Unit (IMU) for a test flight in space. This unit will be delivered in fy '01.

Draper Laboratory has been contracted to study Microgyro performance as a function of bandwidth and dynamic range. Microgyro systems currently have bandwidths of over 100 Hz and dynamic ranges of +/- 100 deg/sec or more. Spacecraft requirements for bandwidth are typically less than 10 Hz and requirements for dynamic range are usually about +/- 20 deg/sec. Improvements in performance are expected to be realized by rescaling these parameters.

CONCLUSIONS

The need for very small, low power inertial sensors has driven a large effort to develop microgyros for space use. The short term performance goal of 0.1 deg/hr is expected to be met in fy'01. In parallel, multi axis units are being developed and will be test flown. For the long term, an ultra small Micronavigator is being developed which will perform navigation and attitude functions currently performed by units many times its size. The reality of Nanosatellites is evidenced by the recent award of a Nanosat mission to the GSFC and MEMS rate sensors will be an enabling technology for future Nanosat Missions.

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